Mine Drop Experiment (MIDEX)

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Republic of Korea minesweeper *YMS-516* is blown up by a magnetic mine, during sweeping operations west of Kalma Pando, Wonsan harbor, on 18 October 1950.
From http://www.history.navy.mil/photos/events/kowar/50-unof/wonsan.htm

Acknowledgements

- Chenwu Fan
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- ET1 Adam Dummer
- George Jaksha
- Prof. Chu

Overview

- Mine Warfare Overview
- Important Environmental Parameters for MCM Operations
- Impact Burial Prediction Model
- Mine Drop Experiment Overview
- Hydrodynamic Theory
- Data Analysis
- Conclusion
- Questions

A Shift in Operational Focus

- Breakdown of Soviet Union Forced Change in U.S. Navy Mission Requirements.
- Primary Guiding Documents: … From the Sea, Forward … From the Sea, Operational Maneuver from the Sea.
- Shift in Mission Focus from Open Ocean to the Littoral.
- Greatest Threat to U.S. Forces Operating in the Littoral: the Naval Mine.

Naval Mine Characteristics

Characterized by:
- *Method of Delivery*: Air, Surface or Subsurface.
- *Position in Water Column*: Bottom, Moored or Floating.
- *Method of Actuation*: Magnetic and/or Acoustic Influence, Pressure, Controlled or Contact.

- Composed of metal or reinforced fiberglass.
- Shapes are Typically Cylindrical but Truncated Cone (Manta) and Wedge (Rockan) shaped mines exist.

Naval Mine Threat

Inexpensive Force Multiplier

Roberts (FFG-58), Tripoli (LPH-10), Princeton (CG-59)
Damages $125 Million;
Mines Cost $30K

Widely Available

- Over 50 Countries
  (40% Increase in 10 Yrs)
  - Over 300 Types
    (75% Increase in 10 Yrs)
  - 32 Countries Produce
    (60% Increase in 10 Yrs)
  - 24 Countries Export
    (60% Increase in 10 Yrs)

Numerous Types

WWII Vintage to Advanced Technologies (Multiple Sensors, Ship Count Routines, Anechoic Coatings Non-Ferrous Materials)

Important Environmental Parameters for MCM Operations

- Water Properties
- Weather
- Beach Characteristics
- Tides and Currents
- Biologics
- Magnetic Conditions
- ❖ Bathymetry (Bottom Type)

Impact Burial

- Mine Impacting Bottom will Experience a Certain Degree of "Impact Burial (IB)".

  - Highest Degree of IB in Marine Clay and Mud.
  - IB Depends on Sediment Properties, Object's Impact Orientation, Shape and Velocity.

- MCM Doctrine Provides only a Rough Estimate of IB.

Bottom Composition	Predicted Mine Case Burial %	Bottom Roughness	Bottom Category
Rock	0	Smooth	B
		Moderate	C
		Rough	C
MUD OR SAND	0 TO 10	Smooth	A
		Moderate	B
		Rough	C
	10 TO 20	Smooth	A
		Moderate	B
		Rough	C
	25 TO 75	Smooth	A
		Moderate	B
		Rough	C
	75 TO 100	All	C

Development of Navy's Impact Burial Prediction Model (IBPM)

- IBPM was designed to calculate mine trajectories for air, water and sediment phases.
- Arnone & Bowen Model (1980) – Without Rotation.
- Improved IBPM (Satkowiak, 1987-88) – With Rotation.
- Final Improvements made by Hurst (1992):

  - More Accurately Calculates Fluid Drag and Air-Sea and Sea-Sediment Interface Forces.

  - Treats Sediment as Multi-Layered.

Impact 25

- Main Limitations:

  1. Model assumes mine body is of uniform density, thus center of buoyancy coincides with center of mass.

  2. Model numerically integrates momentum balance equations only. Does not consider moment balance equations.

- If a mine's water phase trajectory is not accurately modeled, then IB predictions will be wrong.
- Recent sensitivity studies by (Chu et al., 1999, 2000, Taber 1999, Smith 2000) have only focused on sediment phase calculations.

MIDEX

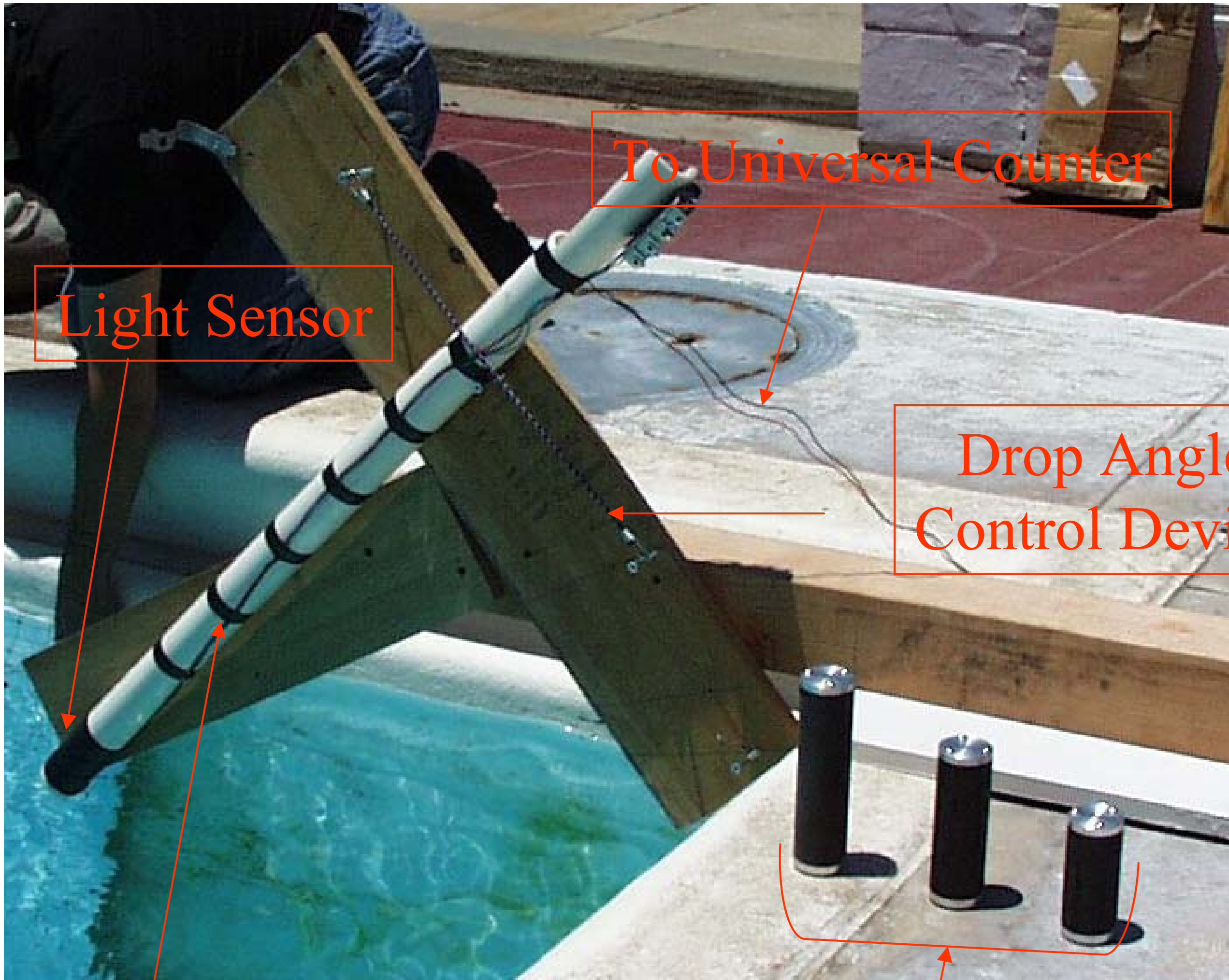
- MIDEX designed to examine the uniform density assumption of IMPACT 25, namely what effect a varying center of mass will have on a mine shape's water phase trajectory.
- Controlled Parameters:

  1. Drop Angles: 15º, 30º, 45º, 60º, 75º.

  2. Center of Mass Position.

  3. L/D ratio (constant).

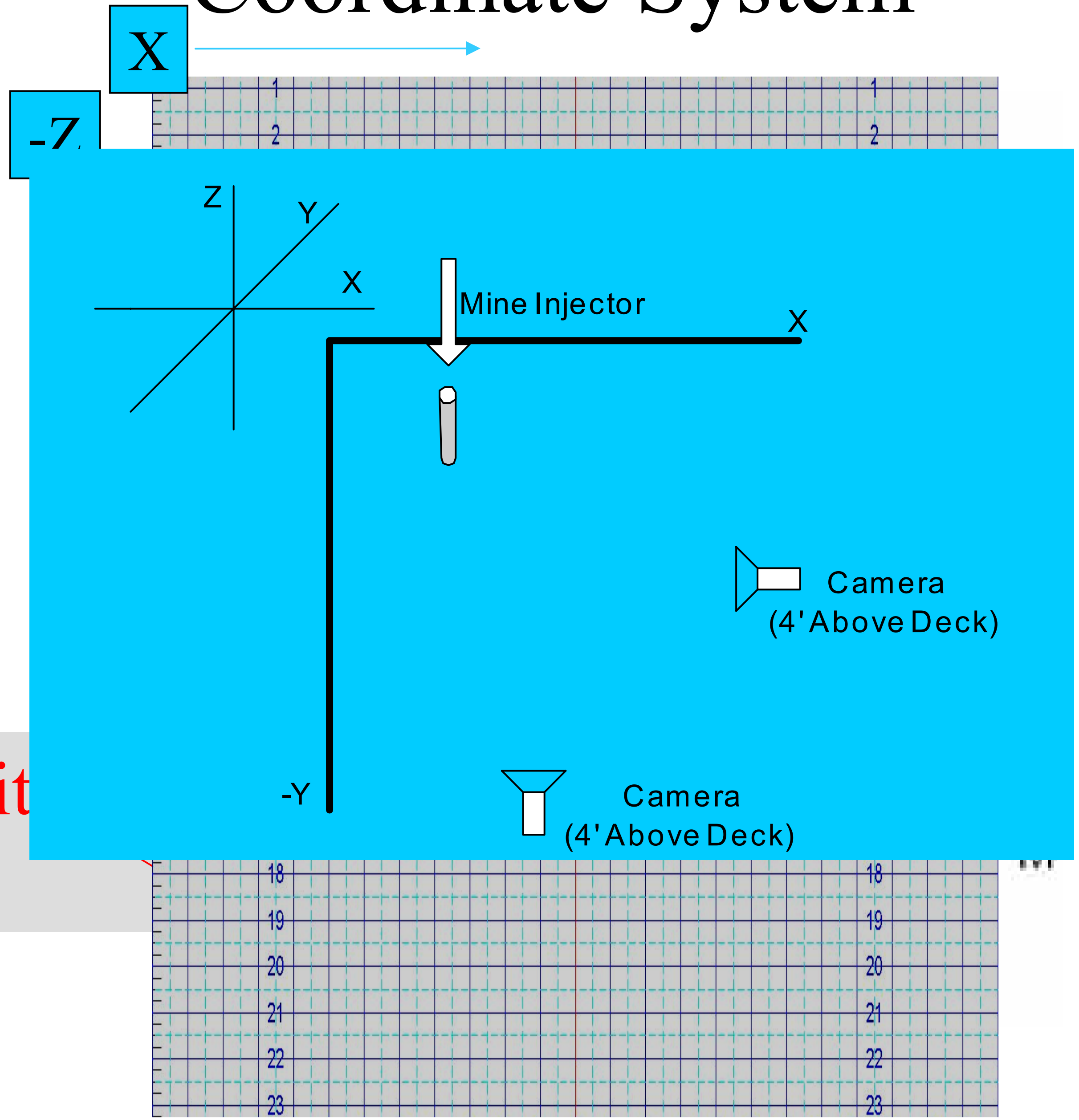
  4. V_{init} (to some extent).
- Conducted several tests for each drop angle, center of mass position and initial velocity.



Mine Injector

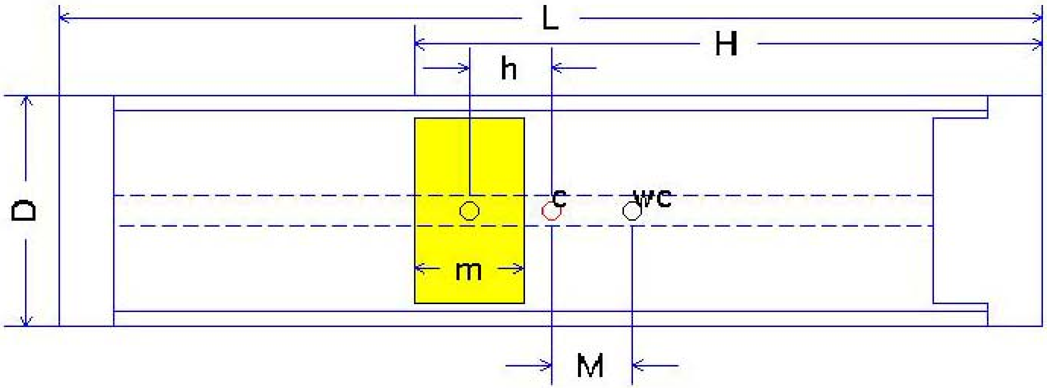
Mine Shapes:
Length: 15, 12, 9 cm
Diameter: 4 cm

Coordinate System



Mine Attit
(Psi)

Center of Mass



MODEL # 1

L=15.1359cm D=4cm m=2.7cm

Weight=322.5 g Volume=190.2028 cm^3 Density=1.6956 g/cm^3

H:	10.380	8.052	5.725	cm
h:	−1.462	0.866	3.193	cm
M:	0.000	18.468	36.935	mm

MODEL # 2

L=12.0726cm D=4cm m=1.7cm

Weight=254.2 g Volume=151.709 cm^3 Density=1.6756 g/cm^3

H:	8.450	6.609	4.768	cm
h:	−1.564	0.277	2.119	cm
M:	0.000	12.145	24.290	mm

MODEL # 3

L=9.1199cm D=4cm m=1.47cm

Weight=215.3 g Volume=114.6037 cm^3 Density=1.8786 g/cm^3

H:	6.662	5.592	4.521	cm
h:	−1.368	−0.297	0.774	cm
M:	0.000	6.847	13.694	mm

Defined COM position as:

2 or -2: Farthest from volumetric center

1or -1

0: Coincides with volumetric center

Hydrodynamic Theory

- Solid Body Falling Through Fluid Should Obey 2 Physical Principles:

1. <u>Momentum Balance</u>

$$\int (dV^* / dt^*) dm^* = W^* + F_b^* + F_d^*$$

2. <u>Moment of Momentum Balance</u>

$$\int [r^* \times (dV^* / dt^*)] dm^* = M^*$$

* Denotes dimensional variables

V^* → Velocity

W^* → gravity

F_b^* → buoyancy force

F_d^* → drag force

M^* → resultant moment

Hydrodynamic Theory

- Considering both momentum and moment of momentum balance yields 9 governing equations that describe the mine's water phase trajectory.

$$\boxed{\frac{dV_1}{dt}+\omega_2V_3-\omega_3V_2=-\frac{C_D\rho_w}{2\rho_m}|\vec{V}|(V_1-V_{w1})+\frac{\rho_m-\rho_w}{\rho_m}\cos\psi_1}$$

$$\boxed{\frac{dV_2}{dt}+\omega_3V_1-\omega_1V_3=-\frac{C_D\rho_w}{2\rho_m}|\vec{V}|(V_2-V_{w2})+\frac{\rho_m-\rho_w}{\rho_m}\cos\psi_2}$$

$$\boxed{\frac{dV_3}{dt}+\omega_1V_2-\omega_2V_1=-\frac{C_D\rho_w}{2\rho_m}|\vec{V}|(V_3-V_{w3})+\frac{\rho_m-\rho_w}{\rho_m}\cos\psi_3}$$

$$\boxed{J_1\frac{d\omega_1}{dt}+(J_3-J_2)\omega_2\omega_3-J_{31}(\frac{d\omega_3}{dt}+\omega_1\omega_2)=\frac{LM_1^*}{g}}$$

$$\boxed{J_2\frac{d\omega_2}{dt}+(J_1-J_3)\omega_3\omega_1-J_{31}(\omega_3^2-\omega_1^2)=\frac{LM_2^*}{g}}$$

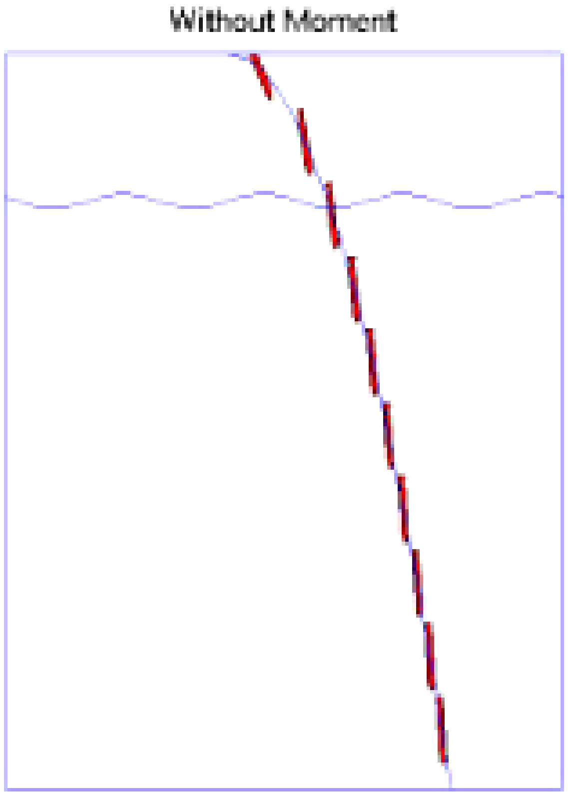
$$\boxed{J_3\frac{d\omega_3}{dt}+(J_2-J_1)\omega_1\omega_2-J_{31}(\frac{d\omega_1}{dt}-\omega_2\omega_3)=\frac{LM_3^*}{g}}$$

$$\boxed{\frac{d}{dt}\cos\psi_1=\omega_3\cos\psi_2-\omega_2\cos\psi_3}$$

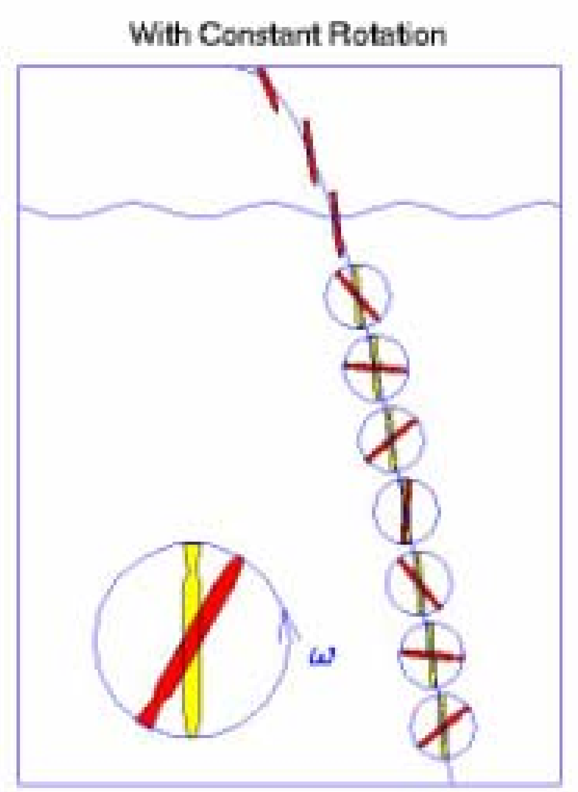
$$\boxed{\frac{d}{dt}\cos\psi_2=\omega_1\cos\psi_3-\omega_3\cos\psi_1}$$

$$\boxed{\frac{d}{dt}\cos\psi_3=\omega_2\cos\psi_1-\omega_1\cos\psi_2}$$

Hydrodynamic Theory



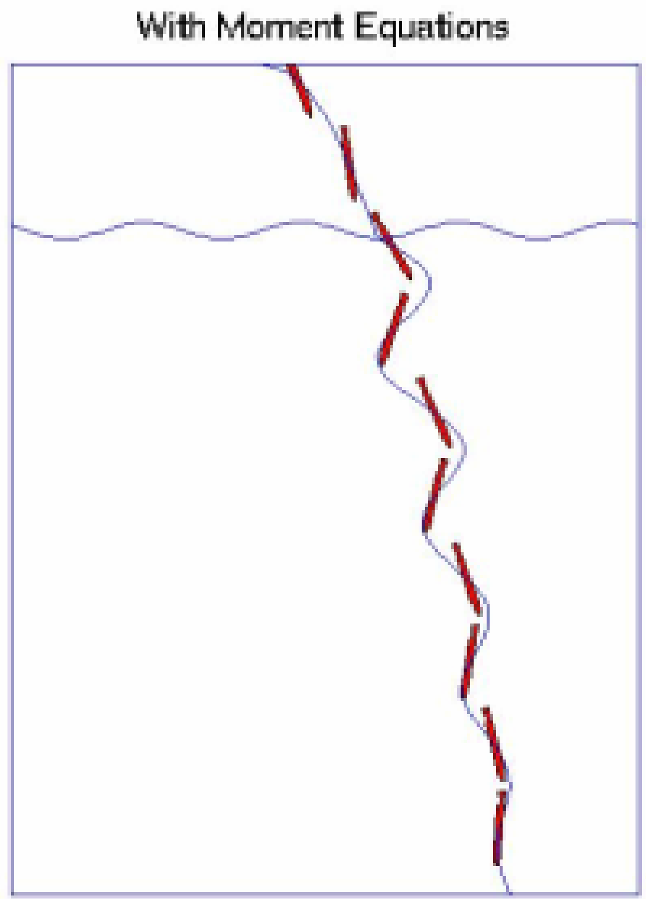
Arnone-Bowen IBPM
Without Moment Equation



Improved IBPM with rotation but
without Moment Equation

Hydrodynamic Theory

- By considering both equations mine will exhibit a spiral fall pattern.



Data Analysis

1. Video converted to digital format.
2. Digital video from each camera analyzed frame by frame (30Hz) using video editing program.
3. Mine's top and bottom position determined using background x-z and y-z grids. Positions manually entered into MATLAB for storage and later processing.
4. Analyzed 2-D data to obtain mine's x,y and z center positions, attitude (angle with respect to z axis) and u,v, and w components.

Non-dimensional Conversions

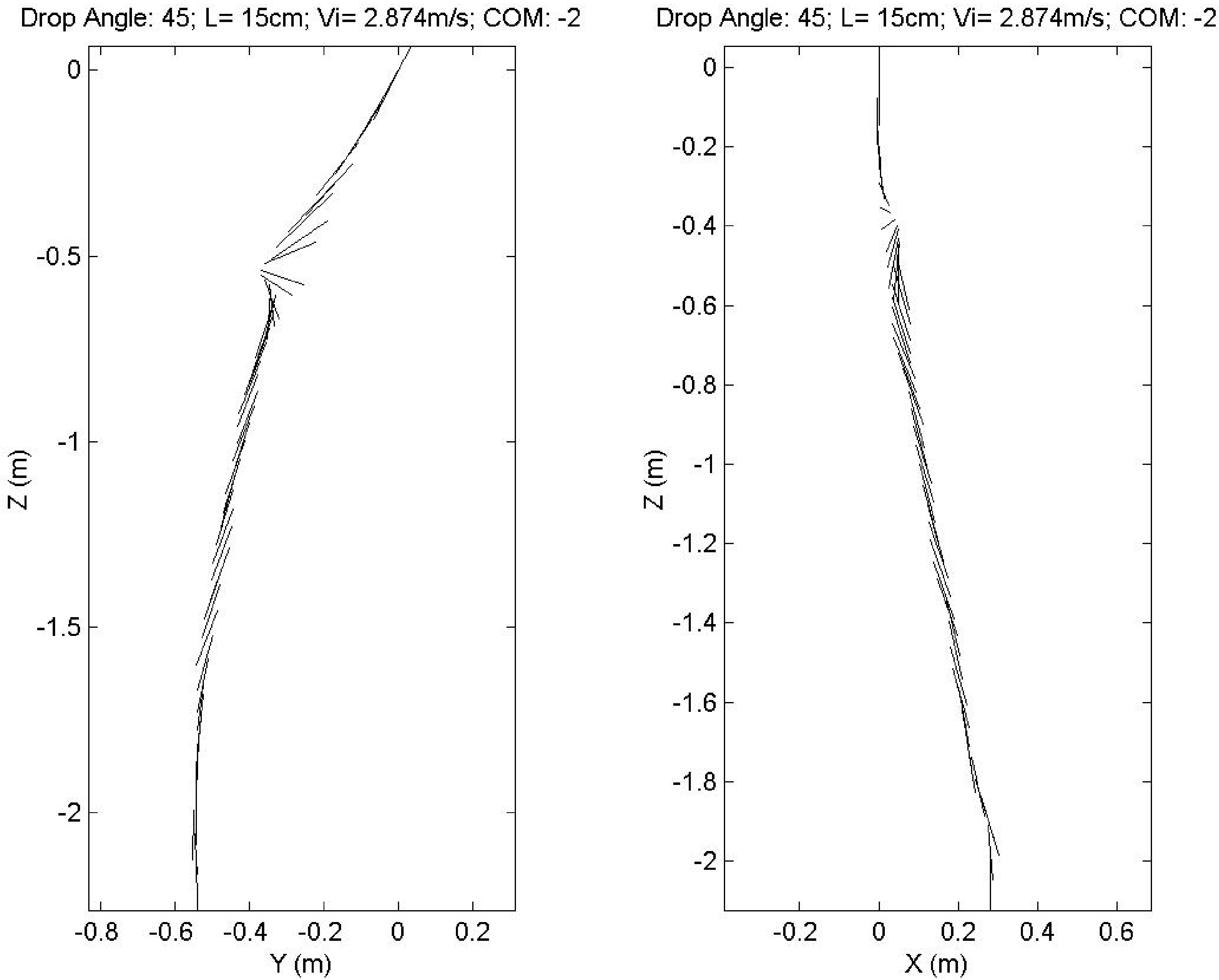
- In order to generalize results, data was converted to non-dimensional numbers.

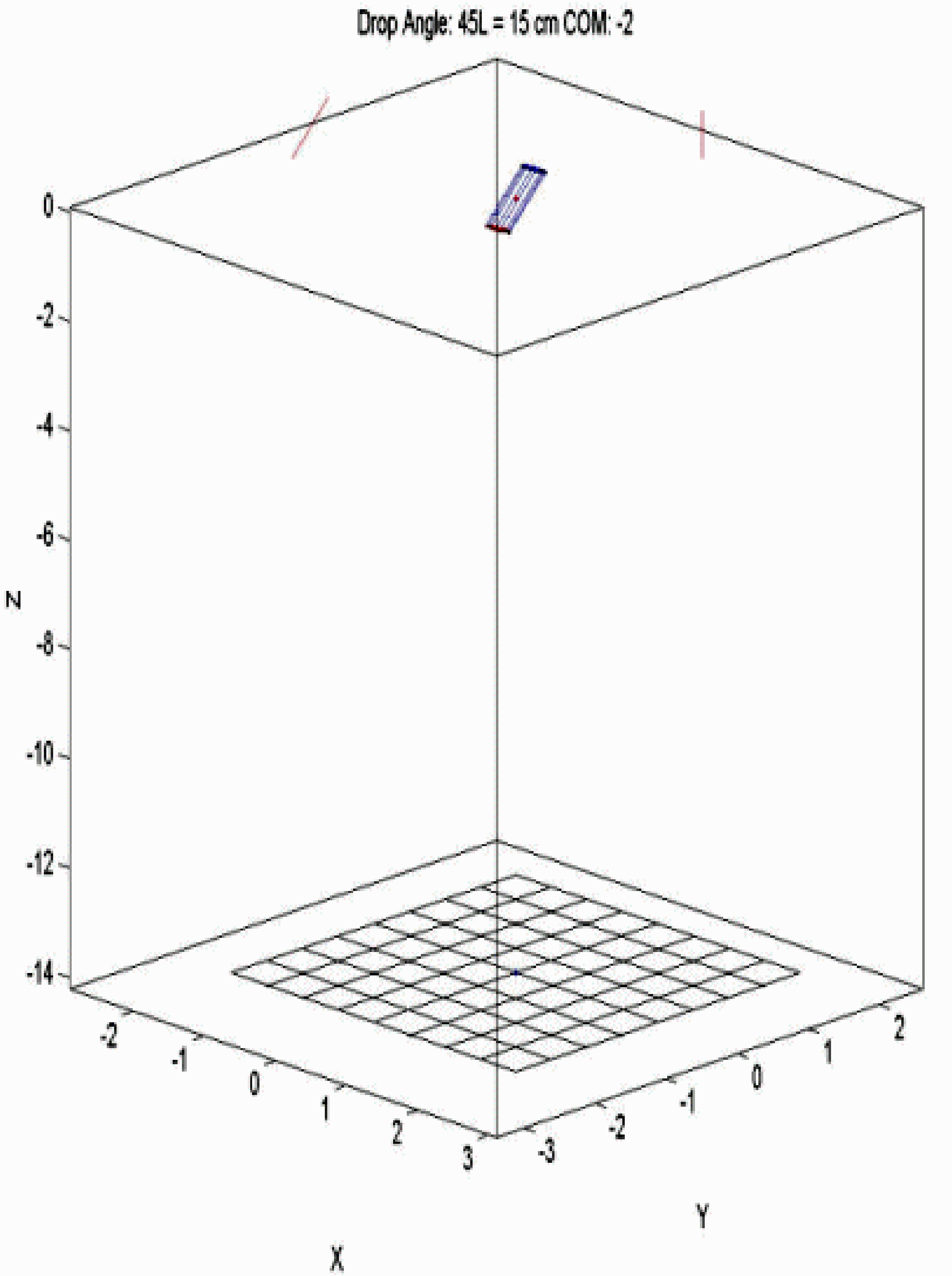
$$t^{*} = \frac{dt}{\sqrt{\frac{L}{g}}},\ V_{i}^{*} = \frac{V_{i}}{\sqrt{gL}},\ \frac{L}{D},\ COM = \frac{2\Delta L}{L},\ \frac{(x,y,z)}{L},\ \frac{(u,v,w)}{\sqrt{gL}}$$

Sources of Error

1. Grid plane behind mine trajectory plane. Results in mine appearing larger than normal.
2. Position data affected by parallax distortion and binocular disparity.
3. Air cavity affects on mine motion not considered in calculations.
4. Camera plane not parallel to x-y plane due to pool slope.

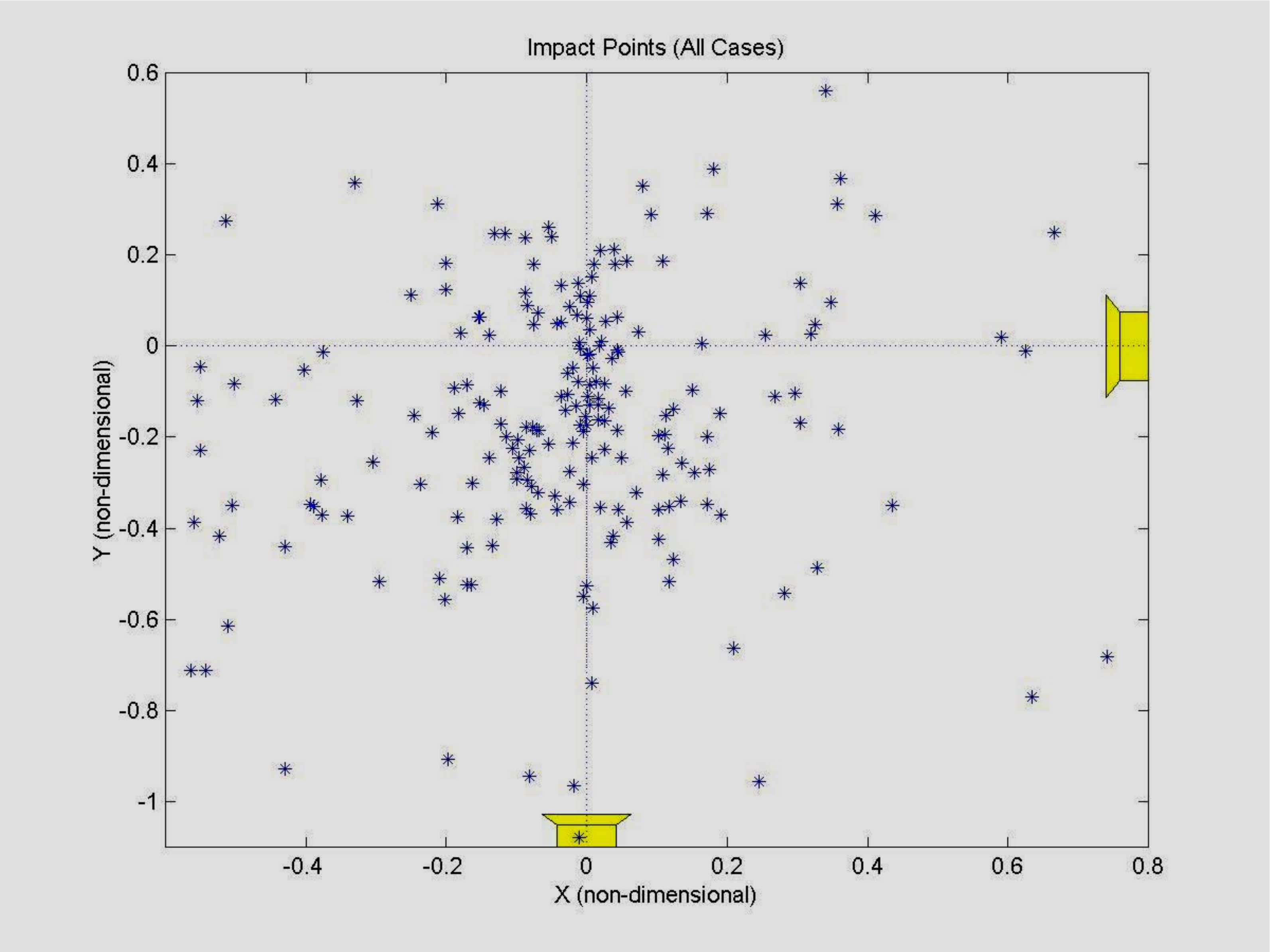
Underwater Video Clip


Drop Angle: 45; L= 15cm; Vi= 2.874m/s; COM: -2
0
-0.5
-1
-1.5
-2
Z (m)
-0.8
-0.6
-0.4
-0.2
0
0.2
Y (m)
Drop Angle: 45; L= 15cm; Vi= 2.874m/s; COM: -2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
Z (m)
-0.2
0
0.2
0.4
0.6
X (m)

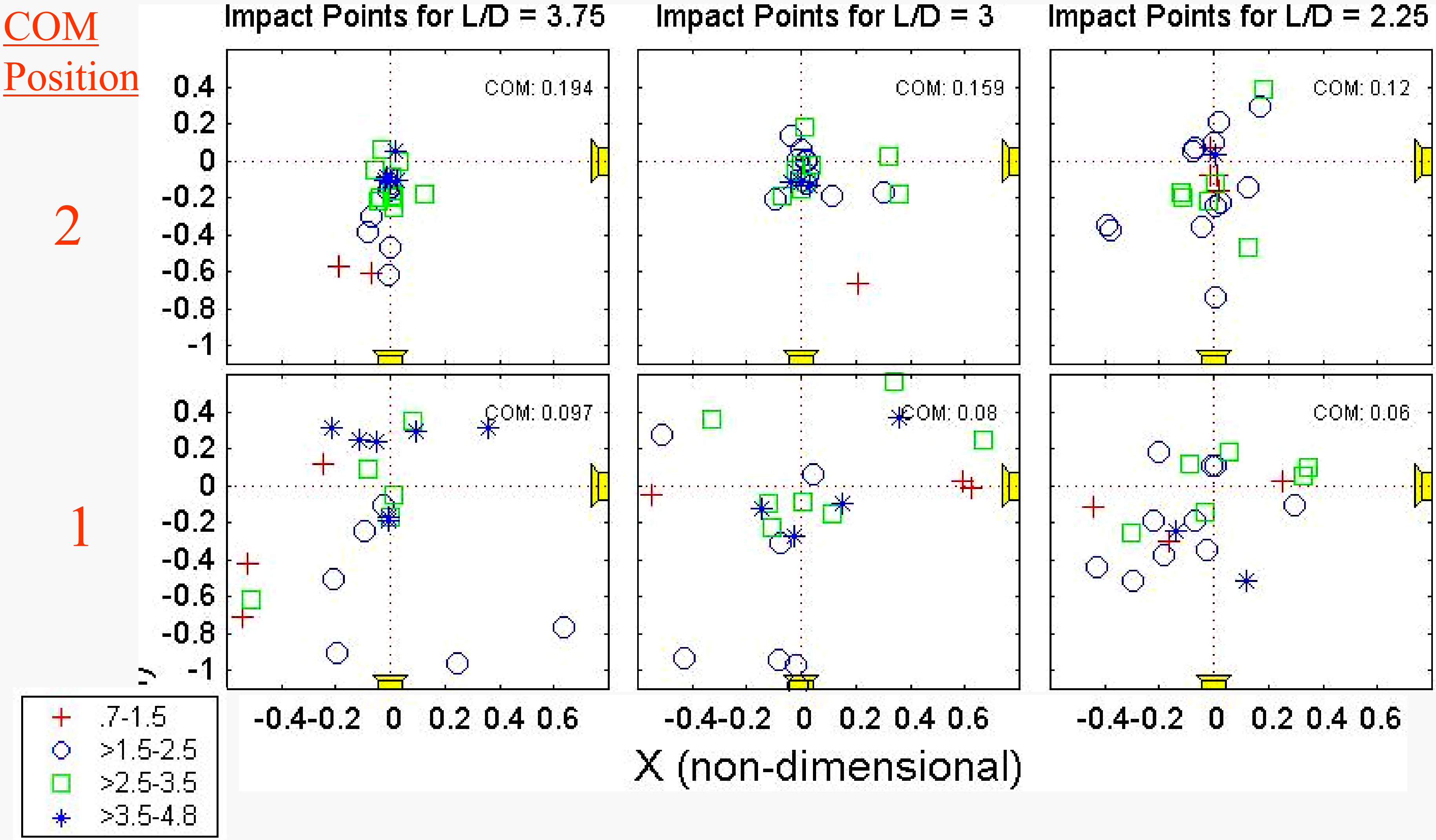


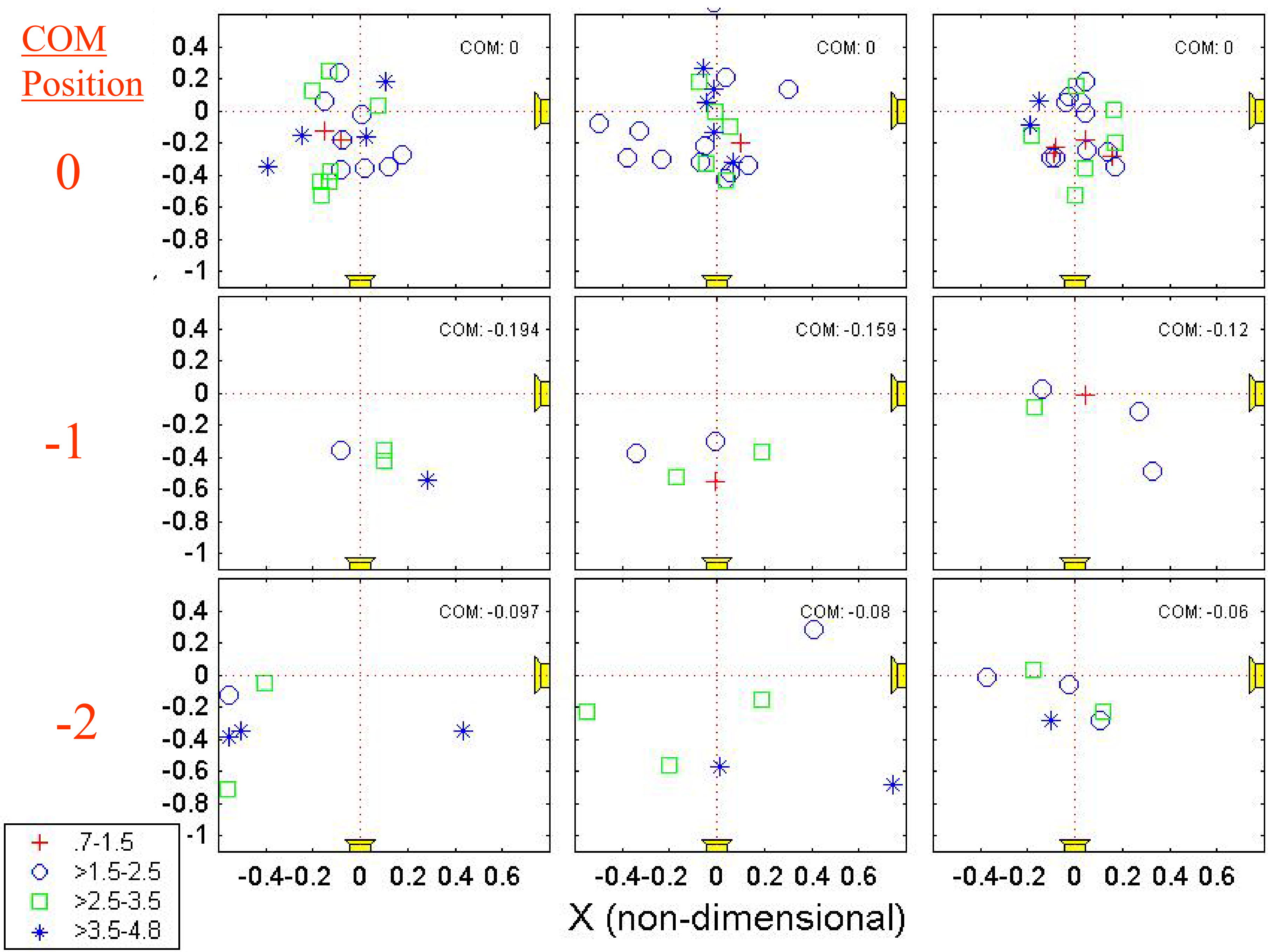
Drop Angle: 45L = 15 cm COM: -2
0
-2
-4
-6
-8
-10
-12
-14
Z
-2
-1
0
1
2
3
X
-3
-2
-1
0
1
2
Y

Impact Point (All Cases)



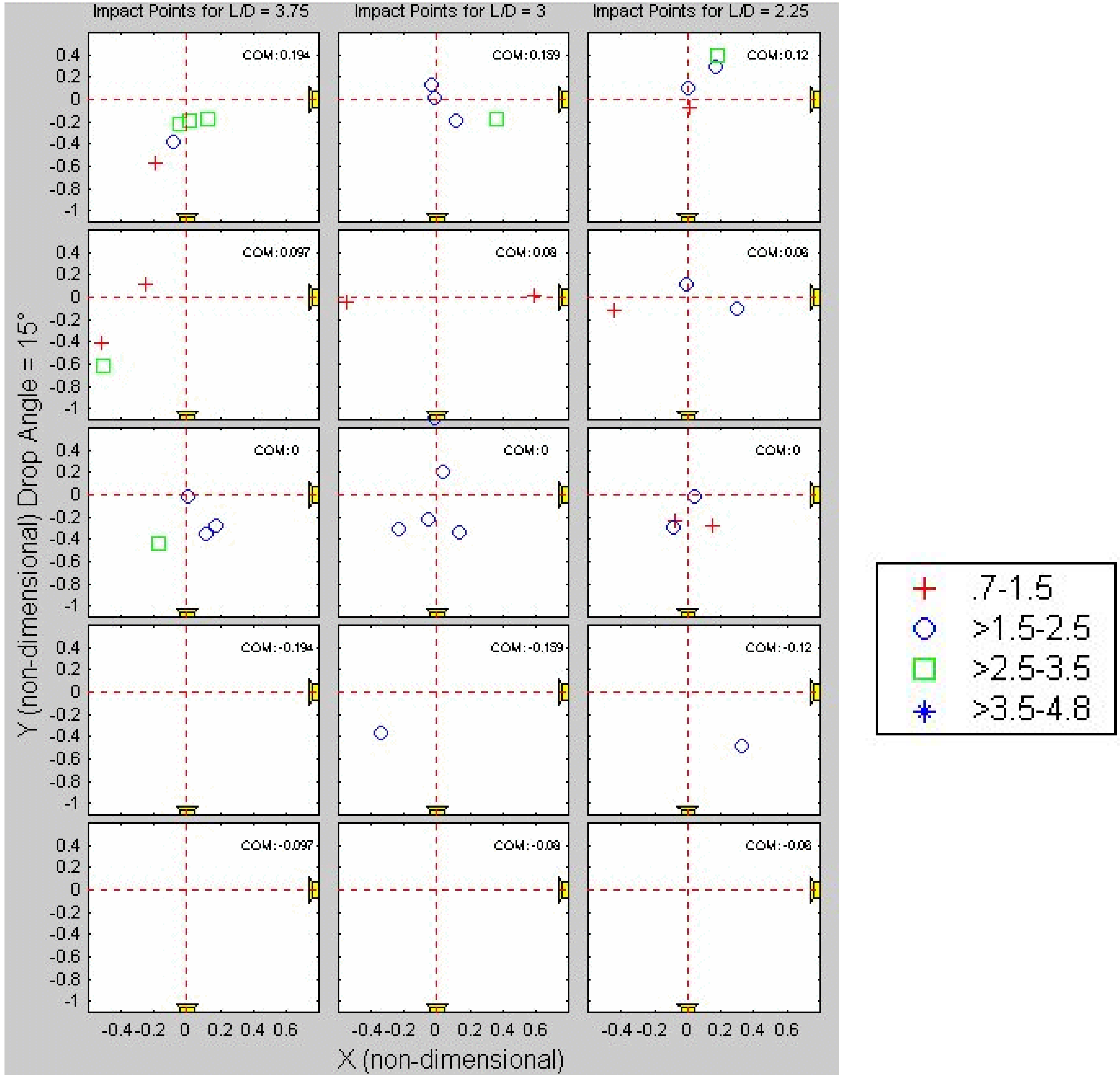
Impact Point (All Drop Angles)



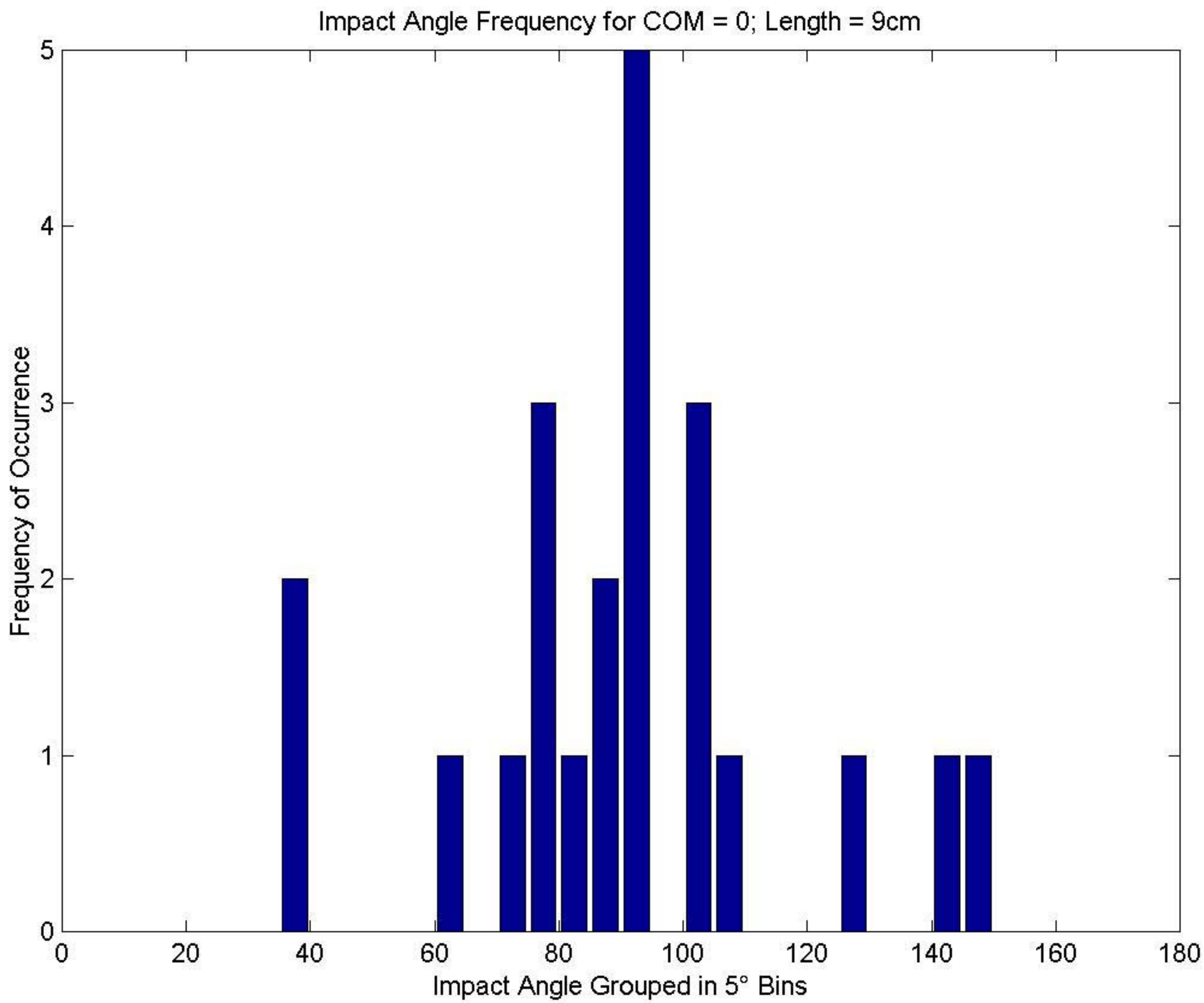


COM Position
0
-1
-2
COM: 0
COM: -0.194
COM: -0.159
COM: -0.12
COM: -0.097
COM: -0.08
COM: -0.06
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.4-0.2 0 0.2 0.4 0.6
X (non-dimensional)
.7-1.5
>1.5-2.5
>2.5-3.5
>3.5-4.8

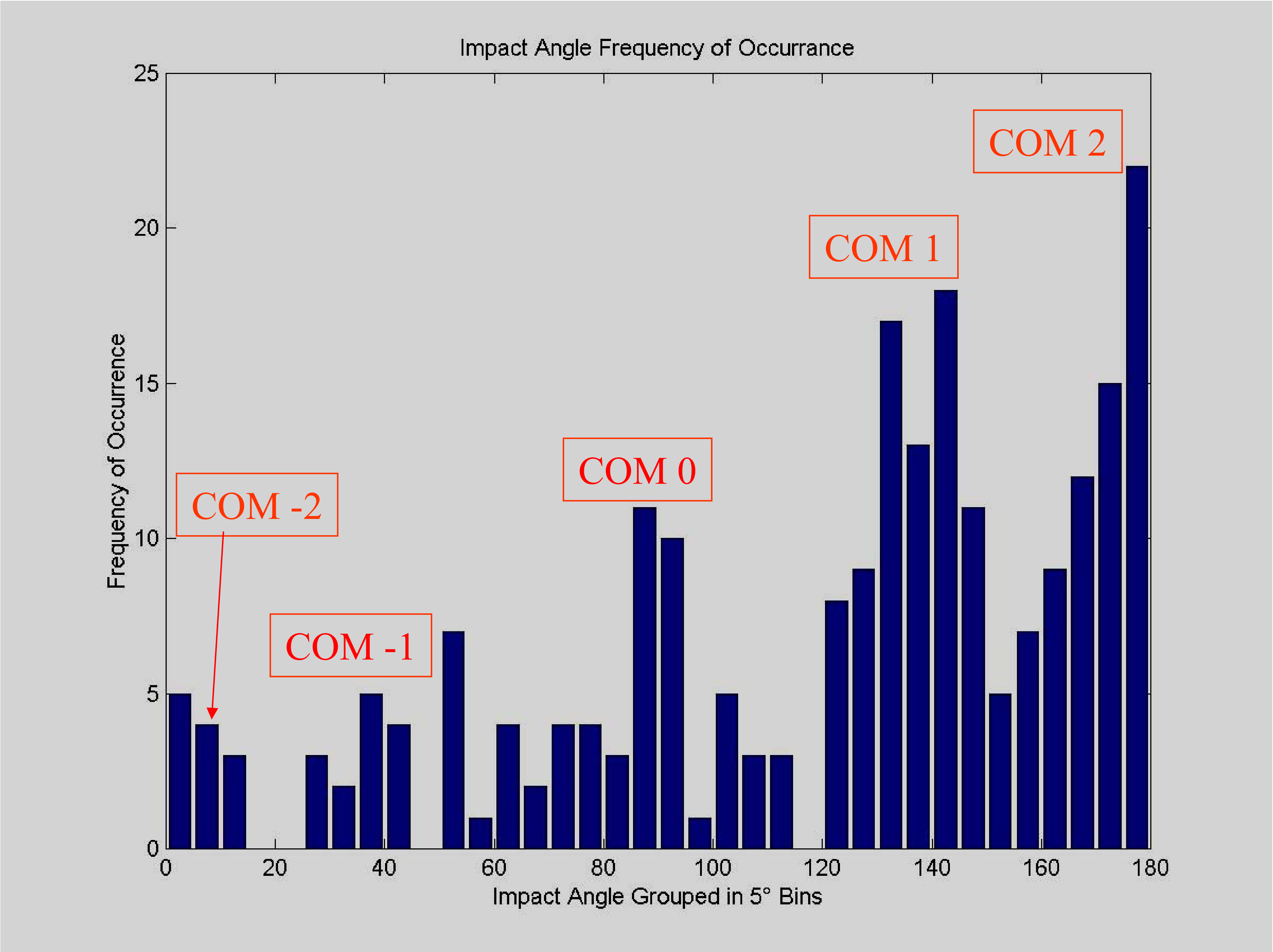
Impact Point (By Angle)



Impact Angle Frequency of Occurrence by L

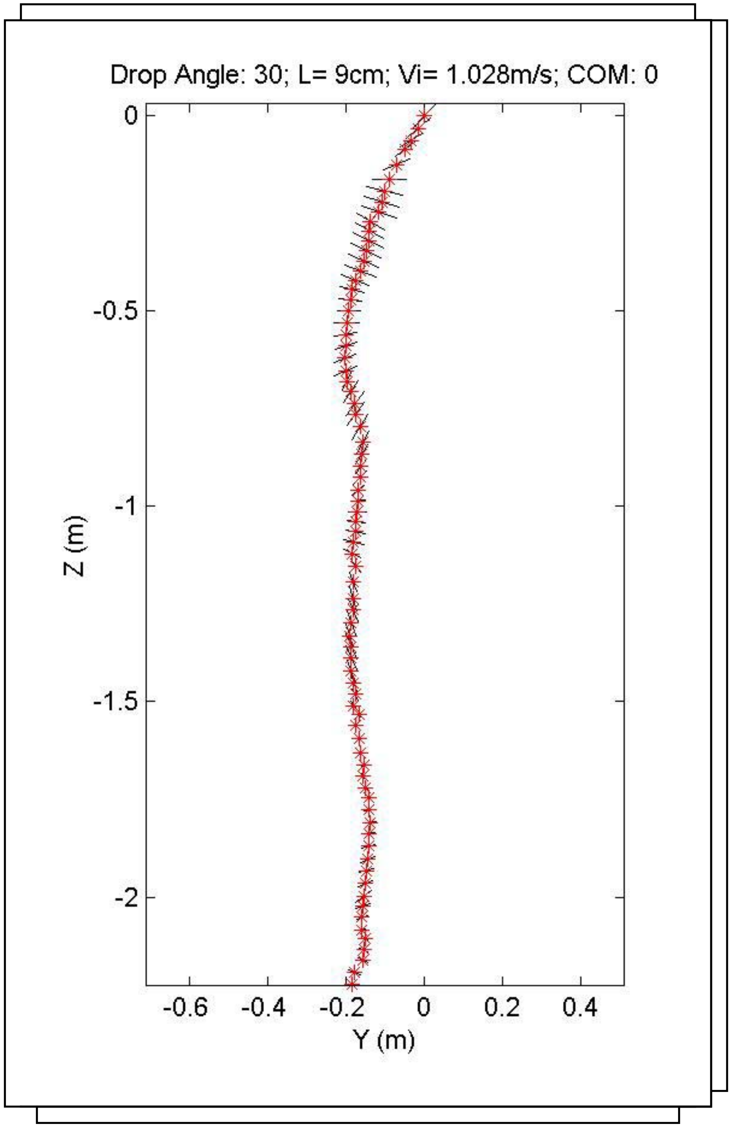


Impact Angle Frequency of Occurrence



Trajectory Patterns

1. Straight
2. Slant
3. Spiral
4. Flip
5. Flat
6. See Saw
7. Combination



Multiple Linear Regression

- General Multiple Linear Regression Equation:

$$f_{\imath} = \beta_0 + \beta_1 x_{1\imath} + \beta_2 x_{2\imath} + \beta_3 x_{3\imath} + \beta_4 x_{4\imath} + \varepsilon_i$$

- Used least squares solution to determine correlation coefficients.
- Input: cos(drop angle); L/D; V_{ind}; COM_{nd}
- Output: (x_m, y_m, z_m, Psi, u, v, w)

Multiple Regression Results

	x_m	y_m	Psi	u	v	w
β_0	-.0746	-.0546	102.5691	.0040	-.0135	-.9481
β_1	.1190	-.0828	-13.3508	-.0075	-.0106	-.1080
β_2	-.0469	-.0798	-.5009	-.0011	.0005	.0295
β_3	.0372	.0622	1.0437	.0025	.0011	-.0221
β_4	.2369	.4330	472.2135	-.0090	.0537	-1.2467

- Most important parameter for impact prediction is Psi (impact angle).

Check of regression equation:

Determine Psi for case where:

L=15cm, V_i = 3m/s, COM = 2, Drop Angle = 15°

Yields: Psi = 181.2°

For COM = 1: Psi = 136.1°

For COM = 0: Psi = 90.4°

Conclusion

- COM position is the most influential parameter for predicting a mine’s impact position and angle.
- Final velocities were lowest for COM 0 cases due to the increased effect of hydrodynamic drag.
- Trajectories became more complex as L/D decreased (9 cm mine rotated about z-axis).
- Observed trajectory patterns were more complex than those assumed by IMPACT 25. Accurate representation of a mine’s water phase motion requires both momentum and moment of momentum equations.